

A marked increase in the percentage of dead granulocytes was observed only in suspensions irradiated at 5 mW/cm²....

Irradiation of erythrocytes and granulocytes in vitro resulted in marked injury of cell membranes. After 15 minutes irradiation with 10cm waves at 1 mW/cm², increased potassium concentration in the supernatant was observed. This was followed by decreased osmotic resistance of the cells and increased cell membrane permeability for haemoglobin at higher power densities.

Injuries of the cell membrane function seems to be time and dose dependent.

In granulocytes irradiated at 5 mW/cm² a rapid increase in the percentage of dead cells was seen while at 1 mW/cm² partial liberation of the hydrolases was the only phenomenon observed during 60 minutes of irradiation.

The decreased osmotic resistance and increased permeability of cell membranes are probably the consequence of earlier disturbances in the sodium potassium pump and are the signs of an irreversible injury of the cell membrane leading to the death of cells. [86]

In the light of the work mentioned above Stodolnik-Baranska irradiated cultured human lymphocytes using, respectively, 2950MHz at 7 mW/cm² constant or 20 mW/cm² pulsed 1200Hz 1µsec pulse. The irradiation was for 4 hours a day at 7 mW/cm² for 3-5 days and for 15 minutes daily at 20 mW/cm² for 3-5 days..

Radiofrequency exposure at 20 mW/cm² induced changes in the mitotic index which depended on exposure time...

. significant differences between exposed and controls were seen following 20 and 40 minute exposures. Similar results were obtained following 3- 4 hour exposure at 7 mW/cm². The mitotic index was approximately two times higher in irradiated samples than in controls.... It should be pointed out that changes in chromosomal morphology suggesting changes in spiralisation were the most unusual finding. [87]

Similar pictures were observed in chromosomes of irradiated rat kangaroo cells by Yao and Jiles. These authors call such changes "electromagnetic degeneration of chromosomes" [88]

Phagocytic forms containing nuclear fragments or phagocytised chromosomes were encountered. Moreover fragmentation of nuclei and nuclear vacuolation were seen. Certain pictures recalled cells in amitosis. Nuclear bridges were also not infrequent. The highest number of chromosomal aberrations was seen after exposure during the

70th hour of incubation. In this instance the number mitosis with chromosomal aberrations reached 50%.

MECHANISMS

In the 1960s various hypothesis had been advanced within Soviet science to explain the physical nature and mechanisms of the nonthermal effects.

The chain of pearls theory was one such theory, based on the observation that droplets of a liquid or solid particles suspended in another liquid arrange themselves into chains orientated along the lines of force in a radio frequency field. The orientation of the suspended particles is explained by the fact that charges are induced in them under exposure to the field. Electrostatic attraction is what causes the stringing of the particles. It is believed that the chain of pearls phenomena is of nonthermal nature, since it is weakened by increasing the field strength whereupon the temperature rises.

The theory of nonthermal denaturation of proteins was first advanced in 1940 by V I Romanov. [48] He suggested that polar molecules are not rigid dipoles as was assumed but elastic ones. This makes it possible for parts of the molecules to shift in an electromagnetic field. A medium composed of such elastic molecules would be a medium composed of resonators. Electromagnetic waves could be absorbed in this medium if their periods coincided with the natural vibration period of the dipoles.

Such effects might also occur at superhigh frequencies and transition of molecules to excited states was possible. In the 1950's and early 1960's it was proposed that such phenomena may also be possible in certain parts of protein molecules. Here hydrocarbon and other bonds might be disrupted as the result of the forced orientational vibrations of the protein molecules. The hydration zone determining the solubility of the molecules might also change. Either rupturing of intramolecular bonds due to resonance forces or changes in hydration zones could ultimately lead to nonthermal denaturation of the protein.

Russian scientists thought it was possible that the action of non-thermal radiofrequency fields is brought about with water molecules as an intermediary; vibrating under exposure to the electromagnetic fields these molecules can produce disturbances in the strictly regulated rhythm of metabolic processes in the cell which take place in the aqueous phase. This hypothesis was most favoured because the nonthermal effect of

electromagnetic fields was observed not only in the radiofrequency band but also at lower frequencies.

Radiofrequency caused changes in the permeability of cell membranes was proposed by A S Presman in 1963. [89] The mechanism he proposed was a change in the sodium potassium gradient in the water that hydrates the protein molecules in the surface layer of the cell membranes. Presman also postulated that electromagnetic fields give rise to regulatory process in the living organism alongside the nervous reflex and hormonal processes, that the means of communication between cells and in interactions of organs and systems is electromagnetic in nature and that this system might be disrupted by radiofrequency irradiation.

In the West, particularly the USA, the emphasis on studies on tissue and cell damage by high-energy radiation led to neglect of the occurrence of cooperativity in biological systems and the important role it may play in the interactions of tissues with non-ionising electromagnetic fields [90]Adey, 1990). It also neglected the well-known effect of these fields on chemical interactions involving free radicals. Originally seen as an intermediary in tissue damage produced by ionising radiation, free radical production is now recognised as an accompaniment to many biological processes where mechanisms have evolved to minimise any damage it may cause. Applied electromagnetic fields, however, cause radicals that would otherwise react to drift apart or closer together, depending on the strength and frequency components of the field. This has been shown in the well-known RYDMR (reaction yield magnetic resonance) effect which can be demonstrated at radio and radiofrequency frequencies. Typically, a photochemical reaction is made to occur which will emit a detectable fluorescence and modulation of the reaction with an applied electromagnetic field can be followed by measuring the changing fluorescence McLauchlan and Steiner, 1991, [91]Ulrich and Steiner, 1989).[92] The fields involved are very weak indeed, the magnetic component being only a few mT. McLauchlan himself [93](1992) has called attention to the implications of this effect in biology and medicine and has emphasised the complexity of the responses likely to be provoked by these very weak fields. A third, more speculative, mechanism, has been suggested by Tilingier [94](1981) in that, at frequencies in the 10 - 10,000 GHz range, resonant vibrational or rotational interactions may occur in biological macromolecules or their segments. We, therefore, have three possible explanations for the variety of effects observed when cells and tissues are exposed to low-strength, low-energy electromagnetic radiation.

The cooperativity mechanism points, primarily, to short term disturbances arising from interference of the fields with signalling between cells, although there could be epigenetic effects which would be long term. The RYDMR effect, on the other hand, is likely to be more long-term, involving as it does the possibility of enhancing free radical-invoked damage to DNA. The vibrational effect is more likely to occur at sharply resonant frequencies and could have short and long term effects by, say, modifying the allosteric or the active sites of enzymes. Gründler et al [95](1992) have attempted to synthesise these approaches by proposing models of a sequence of events beginning with electromagnetic field transductive coupling, based on magnetic field dependent reactions, including cytochrome reactions involving transient radical pairs and the production of further free radicals, such as nitric oxide or reactive oxygen, leading to a further highly cooperative amplification step. Arguing from Fröhlich's [96](1986) model of interactions between an imposed field and high frequency (1 GHz) intracellular van der Pol oscillators, they proposed that imposed fields can be active at intensities near zero.

THE PROBLEMS OF EARLY STUDIES - PARTICULARLY DOSIMETRY

Early studies on the effects of radiofrequency radiation tended to be dominated by thermal considerations and, in the case of whole organisms, the experimental exposures were relatively short term. This applied even when athermal effects were looked for and the literature of the 1960s reported such research, much of it driven by such considerations such as the radiofrequency "zapping" of U.S. Moscow Embassy personnel and research about the possibility of using radiofrequency waves in some way to alter enemy psychological and neurological states in covert operations or even on the battlefield.

With experimental animals both the exposures and the follow-up were relatively brief and in many cases it was difficult to ascertain the dose of radiation actually delivered to each animal. In retrospective epidemiological studies on occupationally-exposed human subjects again ascertaining the dose was very difficult indeed, although the long-term element was more satisfactory. Unfortunately, even assuming that the dosimetry can be got right and the experiments are conducted over a reasonable term, there is an inherent problem in extrapolating radiofrequency effect studies on animals

to human beings which does not occur in studies of most other suspected noxious agents. In the latter studies, compensation for the short life-span of the animal and a safety margin are obtained by administering the agent at a dose at least one or two orders of magnitude greater than the dose to which human beings would be exposed. With radiofrequency waves, unfortunately, such a dose would be in the low thermal range. In the light of this difficulty and of the problems of retrospective human epidemiological studies the only responsible course to take is to design experiments with cells and tissues to elucidate possible mechanisms of biological activity by radiofrequency waves which will enable informed judgements to be made about their effects on human health.

FROM PHENOMENOLOGY TO EXPLANATION

The 1970s and 1980s saw an increase in the numbers of experiments carried out on cells and tissues, both in culture and in intact animals, where careful attention was paid to experimental design and dosimetry. Many of these experiments were, however, phenomenological. They were designed to answer the question of whether radiofrequency radiation had biological effects. In most cases they provided scant information as to how any effects might have occurred. Hence, they had little ability to suggest further experimentation, beyond mere replication, and had no predictive power with respect to the long-term effects of low power radiofrequency radiation on the intact animal, especially Man.

Adey [97](1990) has emphasised the effects of low levels of electromagnetic radiation on communication between cells (the communication paradigm) and has argued strongly for mechanisms which will produce epigenetic effects giving rise to long-lasting alterations in cell function. The arguments put forward by Adey [98](1990) are drawn from a series of reviews and original papers published by Adey in the previous decade (Adey, 1981a, 1981b, 1984, 1986, 1987a, 1987b, 1988a, 1988b, 1988c, 1988d and Adey and Lawrence, 1984 and Adey et al, 1982)[99-112] and show clearly where the gaps in our knowledge lie and attempt to build a theoretical framework for further studies.

It should be noted that there was sufficient interest in the field for a special journal Bioelectromagnetics to be established in 1979 and there is a Society for Bioelectromagnetics. It also should be noted that athermal, pulsed electromagnetic radiation has already been put to practical use in molecular biology.

Electroporation (Waleczek, 1992) is a pulse technique which transiently renders cell membranes permeable to large molecules and supramolecular assemblages that would not otherwise cross them and is used to transfect cells with foreign DNA or to introduce RNA or proteins.

In the papers published on well-defined experimental systems since the late 1970's a range of effects of electromagnetic radiation has been found in different biological systems. Gründler and his colleagues first described the nonthermal effects of millimetre waves on yeast growth Gründler et al, 1977;[113] Gründler and Keilman, 1978)[114] and subsequently showed that resonance effects occurred at a sharp peak at 42 GHz in their system Gründler et al, 1983;[115] Gründler and Keilman, 1983;[116] Gründler and Kaiser, 1992)[117]. Effects on cell growth were observed even at levels as low as 5 pW/cm². They suggested that their results could be explained if yeast cells contained one or more active internal oscillators that are normally coupled to cell growth in an unknown manner, but which are interfered with by an external electromagnetic field. It would be of interest to see if Gründler's studies could be replicated with higher eucaryote cells. Furthermore, it is tempting to speculate that the site of these oscillators could be the mitochondria and that they may be connected with the processes of oxidative phosphorylation which produce free radicals. It is relatively easy to work with isolated mitochondria and their enzyme systems and these should be tested for radiofrequency sensitivity.

Damage to mitochondrial DNA by the free radicals produced during metabolism has been suggested as one of the molecular bases of aging. If the McLauchlan (1992) hypothesis that the RYDMR effect might occur in biological systems is correct we should also be looking for changes in mitochondrial DNA after exposure of cells to radiofrequency fields. A suitable system would be a cell line with disabled DNA repair mechanisms.

Interaction of electromagnetic fields with trans membrane signalling mechanisms, particularly those based on Ca⁺⁺ transport has been widely studied. Much of the work has been done with low frequency fields, but effects have also been demonstrated across the radio frequency spectrum in a number of tissues. Blackman et al [118](1979) found an intensity window in the range of 0.1 - 1.0 mW/cm² for the alteration of Ca⁺⁺ efflux in cultured neurones induced by 16Hz sinusoidally amplitude-modulated RF fields. Dutta et al [119](1984) also observed that unmodulated radiofrequency fields of similar intensity were able to induce Ca⁺⁺ efflux from cultured brain tissue. Lin-Liu and Adey (1982) confirmed that low frequency

amplitude-modulated radiofrequency fields could change Ca^{++} efflux rates from synaptosomes.

Adey (1990) has argued that many of the observed effects on trans membrane signalling

may be due to electromagnetic field-induced impairment of signal transmission through gap junctions. In this connection he quotes work by Fletcher et al [120](1986;1987) who noted that blockage of the entry of α -lymphotoxins and tumour necrosis factor into Chinese hamster ovary cells depended on the strain-dependent ability of these cells to form gap junctions. They found that the tumour promoter, tetra-decanoyl phorbol ester, opened gap junctions to allow entry of the lymphotoxin, which caused dose-dependent cell death through lysis. Weak fields at 450 MHz with a strength of 1.0 -

5.0 mW/cm² sinusoidally amplitude-modulated at 16 Hz enhanced by a factor of 2 the

ability of the promoter to cause cytotoxicity in the presence of the lymphotoxin. The same field, unmodulated did not cause enhancement.

Extrapolation of studies on cells and tissues to intact organisms - implications for setting standards

We discussed above the dosimetric problem of extrapolating the results of radiofrequency exposure studies from experimental animals to human beings. A similar fundamental problem exists in extrapolating from isolated cells and tissues to intact organisms. If one is seeking to compare effects on a target organ of an animal with data collected from cells of that organ in culture one has to be able to relate the dose received by the organ to that used in the culture study. Unfortunately, the absorption of radiofrequency waves by the body increases with increasing frequency and the attenuation of the energy is highly dependent on both the dielectric constant and specific absorptive properties of the anatomical structures lying between the surface and the region of interest. For practical purposes radiofrequency radiation is 99.9% attenuated at an average depth in the body equal to 10% of the wavelength. At 300 MHz this depth is 10 cm, at 3 GHz it is 1cm and so on. At the higher frequencies it will be possible only to achieve pico W levels at the internal organs of even a small animal at the expense of some surface heating. Of course, even in a large animal, such as Man, there are some important tissues that lie close to the surface; the testes, the

structures of the eye and the bone marrow of the sternum to name a few. A further complication arises in extrapolating from cultures to animals in that, while it is relatively easy to control the geometry of the irradiating chamber for the former, rigid geometry is only possible for the latter if they are kept under restraint and or anaesthesia - methods which are unacceptable for long-term experiments. For all of these reasons it is highly desirable that a large safety factor be built into exposure standard for human beings and, in view of some of the in-vitro findings, that the standard be very conservative for pulsed and otherwise modulated sources.

RADIOFREQUENCY SICKNESS; IMPLICATIONS FOR RISK MANAGEMENT

As the lists of electromagnetic radiation cancer litigants rapidly grows in the west it is worth looking back at the work done in Russia which established the concept of Radiofrequency Sickness.

In parallel with their laboratory studies Soviet researchers carried out a number of controlled health surveys amongst workers exposed to radiofrequency radiation. Two groups of exposed workers and controls were studied by Sadcikova. The exposed workers were split into two groups depending on the intensity of their work exposures. Those 1000 workers in the first group were exposed to radiofrequencies up to a few mW/cm^2 . The second group of 180 workers were exposed at lower intensities which as a rule did not exceed several hundredths of a mW/cm^2 .

In both groups of radiofrequency exposed workers the results of neurological and cardiovascular tests were significantly different from the controls. There were more frequent complaints of tiredness, irritability, anxiety, partial loss of memory.

In both groups of exposed workers attention was drawn to various autonomic vascular changes inhibited or expressed dermographism instability of pulse and arterial pressure increasing during functional loading tendency to bradycardia and arterial hypotension. Functional thyroid changes with increased activity occurred not infrequently. Predominant complaints concerned cardiac pain... the heart sounds were dull and functional systolic murmur over the heart apex was present.

Electrocardiographic examination revealed minor disturbances of intraventricular conduction sinus bradycardia and moderate lowering of T deflection. In some cases more pronounced cases of T deflection were observed(lowered smoothed or negative T deflection) in left chest leads accompanied by minor downward displacement of the S-T segment without conspicuous changes in its shape and by increased duration of electric ventricular systole

In a number of cases these changes in T deflection were combined with bradycardia and deceleration of intraventricular conduction which taken

together with complaints of heart pain and hypertensive reactions led to their being taken for myocardial lesions or manifestations of coronary spasm. Autonomic vascular changes in persons of the first group, exposed periodically in the past to radiofrequencies of higher intensities had vagotonic as well as sympathicotonic character while in the second group they were predominantly sympathicotonic.

A tendency to cytopenia was observed in the first group with longer duration of employment. These people showed signs of a qualitative deterioration of erythrocytes, with a tendency to spherocytosis and an increase in acid fragility. Decreased numbers of mature cells of the neutrophilic series and signs of stimulated erythropoiesis were noted in bone marrow smears. Examination of ordinary bone marrow smears and of metaphase plates did not reveal an increased frequency of chromosomal aberrations by comparison with controls. [121]

Sadcikova identified three stages of radiofrequency sickness ; 1. initial, 2. moderately advanced, and 3. advanced with the following main clinical syndromes asthenic (loss of energy and strength, chronic debilitated weakness,) astheno-autonomic with vascular dysfunction of hypertonic type (chronic debilitation with angina pain, raised blood pressure and dysfunction in the group of nuclei which exert control over autonomic functions; water balance, regulation of temperature, appetite and food intake, sleep and certain endocrine functions including the neurosecretary control of the adenohipophysis (anterior lobe of the pituitary) and neurohypophysis (posterior lobe of the pituitary gland)

In advanced cases autonomic vascular disturbances dominated, crises of cerebral and coronary insufficiency progressed and development of ischaemic heart disease and hypertension was observed. [122]

Klimkova-Deutschova describes the findings among workers from a neurological assessment method which investigated the functioning of the extra pyramidal system that is the corticospinal ganglia modulating the background activity of the motor system. This method was developed to evaluate and detect early signs of disturbance in the brain and nervous system. 530 workers from a wide range of industries where exposures to radiofrequency radiation was a feature were examined. This included metal and plastic welders, television technicians, radio transmitting station workers,

research workers, steel workers engaged in tempering steel, The exposures in these diverse groups covered frequencies from 0.5MHz to 30GHz .

There was a statistically significant increase in subjective symptoms reported in workers exposed to cm waves and one of the findings of this work was fatigue, particularly among the radio transmission workers

There was a statistically significant increase in the objective signs of autonomous nervous system disturbances in the radio workers and in workers in research institutions where exposures to frequencies covered the frequency band between 3GHz to 30GHz and also in factory workers whose exposure was to wavelengths from 3 -13 cm. Cerebellar symptoms (motor coordination effects) appeared in the research and factory workers. [123]

RADIOFREQUENCY SICKNESS IN THE WEST

Although radiofrequency sickness was first recognised as a syndrome in the former USSR and Eastern Block countries, the first case of radiofrequency disease to be recognised in a workers' compensation jurisdiction in the west was the case of a New York Telephone Company technician Sam Yannon. Yannon was the radio technician assigned to the tuning and aligning of radiofrequency equipment in the television transmission facility on the Empire State Building. He worked in this job from 1955 to early 1968 when as the New York Workers Compensation Appeal Board, in reviewing a 1981 decision following an appeal against granting compensation noted;

"at the age of 57 he began to suffer a drastic deterioration of his hearing, sight and coordination to such an extent that he was unable to perform his duties and he was placed on disability leave. He was retired on July 1971 and died three years later after a long period of progressive physical and mental deterioration. The hospital records indicate that he suffered from an organic brain disorder or a degenerative central nervous system disease of unknown aetiology".

The decision then goes on to review the case and the evidence of occupational disease before stating;

"Finally upon the entire record and with assistance provided by the applicable presumption we conclude that there is substantial evidence to establish the necessary causal relationship between the decedent's exposure to radiofrequency radiation, the development of the occupational disease and his ultimate death" [124]

There have also been a number of other successful litigants including a successful class action against Boeing Aerospace for workers exposed to radiofrequency radiation who developed leukemia.

This litigation must be looked at in the American context. On the one hand, the control of environmental and workplace hazards in the USA is considerably less prescriptive than in Europe and elsewhere. On the other, it is easier for injured parties to resort to legal action, often receiving punitive damages which are set by juries rather than by the courts. It has been argued that fear of expensive litigation results in effective self-regulation and that, notwithstanding the occasional spectacular awards, the system, overall, is less costly and cumbersome than the enactment and enforcement of detailed regulations. Against this, it would seem morally repugnant to many non-Americans that somebody has to suffer injury, compounded by the trauma of a court case in order to set a *de facto* workplace or environmental standard. These arguments are particularly relevant to attempts to harmonise the Australian standard of radiofrequency exposure with the far less stringent IEEE standard.

Notwithstanding the efforts of a few legal firms it is much more difficult for Australians to seek redress through the courts for injury caused at work or by environmental pollution. In the absence of a contingency fee system many would-be plaintiffs are not even in a position to seek advice about their rights, let alone go to court. Even if the individual does this and is successful, there is no provision for punitive damages or class actions so that this success will not necessarily be a spur to self-regulation. Therefore in a legal system, like ours, which does not permit contingency fees, punitive damages or class actions there is a moral responsibility to set workplace and environmental standards as conservatively as possible and not to follow U.S. practice.

HOW ARE STANDARDS TO BE SET

The current paradigm used in standards setting is still fundamentally the thermal model which has been refined with the development of the concept of the Specific Absorption Rate (SAR)

The method is not fool proof. As was discussed earlier in this paper there are very different absorption rates within layers of tissue. Adey warns that ;

Caution is desirable in evaluating the use of the SAR in terms of averaged values. A major issue is the vitally important question of levels of energy deposition at interfaces represented by tissue discontinuities, these may be structurally gross and macroscopic as at the interface between muscle and bone. They may also occur in a microcosm of molecular dimensions as at the margins of macromolecular domains on membrane surfaces. In either case they might be expected to be the site of enhanced energy deposition not effectively modelled in the general SAR concept and even less in the averaged SAR

Local electrical fields of up to 100 times larger than average fields can be induced around microscopic wedge shaped boundaries between regions with different dielectric constants likely to be present in the human body. [125]

There is also the problems associated with the results from animal experiments to test the safety of the SAR for the standards adopted in the USA. Dr Arthur Guy the Director of the Bioelectromagnetics Laboratory at the Washington School of Medicine and his colleagues microwave irradiated rats in a long term study funded by the USAF. The rats were exposed rats at a SAR of 0.4 W/Kg for 5 years

The US EPA assessed this study very carefully requiring data on each animal to be provided to independent assessors. The EPA agreed with the original investigators that the incidence of tumours at any one site was not remarkably larger than commonly observed in other colonies of this strain and went on to state that their independent data analysis had developed the following conclusions:

The incidence of benign pheochromocytomas of the adrenal medulla was significantly higher in the microwave-exposed group than in controls, but the

incidence was not remarkably higher than in control groups of other Sprague-Dawley rat colonies.

No other single type of tumour was significantly increased by the pulsed microwave treatment.

The incidence of carcinomas alone and combined carcinomas and sarcomas of all sites combined is statistically significant and higher in the treated group than in controls.

The incidence of malignant tumours in the endocrine and exocrine glands as a group was significantly higher in the microwave exposed group than in controls. However the incidence of benign tumours of these organs and the incidence of total benign and malignant tumours were not elevated in the exposed group. Glandular tumours here consist of adrenal cortex, adrenal medulla, thyroid, liver, pituitary, testes, epididymis and pancreas. [126]

This is not the type of unequivocal and safe result to confidently base a human exposure standard on.

In the US EPA review of Guy's work it is stated:

The University of Washington study done at a power density level carefully calibrated to simulate human exposure at the maximum level allowed by the ANSI standard, showed the induction of benign adrenal pheochromocytomas in the exposed groups and no statistically significant elevation at any other site. There is a slight elevation in carcinomas in each of several other glandular organs (pituitary, thyroid, adrenal cortex, pancreas, testes and liver) which is statistically significant if they are all considered as single group.

Combining tumours across these glandular organs is justifiable on the generalised hypothesis that EMF'S affect all tissues in the body and that these glands being specialised to respond to small amounts of specific circulating hormones have cell membrane receptors whose function could be affected by ion currents induced by the external fields...

and the EPA concludes after a discussion of all the possible factors that may be at work by saying;

Therefore regardless of which range of frequency components is biologically effective there is a valid rationale for combining the tumour types as we have done and the University of Washington study can be said to have demonstrated the carcinogenic action of this type of pulsed RF radiation.

[127]

There is doubtless room for argument about this interpretation of the results and in another section of the EPA review document arguments against combining endocrine tumours are canvassed and it is acknowledged that

more than one reviewer found it to be excessively speculative. In view of these opinions we conclude that with our current knowledge there is no persuasive reason based on established laboratory findings to combine the tumours of three glands into a single group. The conclusion is that the finding of a statistically significant excess of malignant tumours in all endocrine and exocrine glands as a group furnishes only minimal evidence of carcinogenicity

[128]

The bottom line remains that if these findings do not provide us with a convincingly safe basis for a human exposure standard.

The maximum permissible level in the US standards are thus not convincingly safe and cannot be accepted as the basis for any increase in the current levels of irradiation allowed in the current Australian Standard.

OTHER ANIMAL EVIDENCE OF CARCINOGENIC ACTIVITY

Prausnitz and Susskind in 1962 microwave irradiated mice using 9270 MHz modulated with 2 microsecond pulses at a pulse repetition rate of 500 pulses per second. The power source was a radar transmitter. A daily irradiation lasting 4.5 minutes at an intensity of 0.1 mW/cm² was used. Two findings of significance were reported. An excess of irreversible testicular degeneration (atrophy with no sperm) was found in the irradiated group and secondly of the animals which died during the experiment there was a significant excess of leukemias. [129]

A more recent and well conducted piece of animal research to assess the carcinogenicity of microwave radiation was carried by the Polish researcher Szmigielski. The BALB/c mice were irradiated 2 hours a day, for 5 - 6 months using 2450 MHz microwave radiation at power density levels of 5 and 15 mW/cm².

These irradiations resulted in accelerated appearance and growth of skin neoplasms induced by benzopyrene suggesting a tumour-promoting activity related to long term exposure to low level MW fields. Exposures at 15 mW/cm² resulted in faster appearance and development of tumours compared with both 5mW/cm² and controls. Exposure of mice to 2450 MHz at the same power densities for 1-3 months resulted in lowering of the natural antineoplastic resistance of the animals, as measured by the number of lung nodules (neoplastic colonies) formed after intravenous injection of a titrated number of viable sarcoma cells. The results obtained after exposure of mice to 2450MHz clearly indicate that irradiation at 15mW/cm² (SAR of 6 - 8 mW/cm²) resulted in a significantly increased number of lung nodules. The increases were also significant at 5mW/cm² compared with control animals but the same effect was found following confinement (over-crowding) of unexposed mice a known stressor for mice and used here as a positive control

[130]

The precise mechanism for this tumour promotion activity was not discovered and further work involving possible mechanisms is in progress.

Szmigielski has however confirmed acceleration of tumour development in microwave exposed mice in two further sets of experiments with mice using two different carcinogens, di-ethyl-nitroso-amine (DENA) and methylcholantrene.

As far as DENA was concerned

a significantly shorter survival time and earlier appearance of tumour growth and appearance of hepatic neoplasms was observed in the exposed animals. A similar acceleration of tumour growth and appearance was noted after administration of methylcholantrene.

Mice were injected subcutaneously with a single dose of this carcinogen, leading to development of sarcomas in 3-4 months.

In groups of animals exposed to 2 hours daily from the day of administration of methylcholantrene the sarcomas appeared in about 2 months and grew faster.[131]

In another experiment Szmigielski tested the reaction of mice to sub carcinogenic doses of 3,4 -benzo-alpha-pyrene (BP).

Mice were depilated and the skin on the back was painted every day with 0.01ml of BP dissolved in a benzene - methanol mixture. Prior to painting, the mice were exposed to for 2 hours to 2450 MHz microwaves at 10mW/cm^2 . Mice treated with BP and without microwave exposures served as controls. The sub carcinogenic dose of BP (the dose leading to the appearance of skin neoplasms in 10 - 20% of the animals was established in earlier trials. A daily dose of 100Micrograms (0.01 ml of 1% solution of BP) resulted in the development of skin neoplasms in almost all mice in 4 - 10 months, while 3 and 10micrograms (0.01 ml of 0.03% and 0.1% BP) respectively applied twice weekly led to the appearance of neoplasms in about 15 % of the treated mice. Thus a subcarcinogenic dose of BP was established as 10micrograms twice weekly and this dose was applied in mice exposed to daily sessions of 2450 MHz microwave exposures. It was found that in microwave exposed mice treated with sub carcinogenic doses of BP 40 - 50% of animals exhibited skin neoplasms compared with about 15% in those treated with BP alone. The increased frequency of skin neoplasms in microwave exposed mice treated with sub-carcinogenic doses of BP was qualitatively different from the earlier discussed acceleration of appearance and growth of neoplasms induced by full carcinogenic doses of BP and other carcinogens. Although it still must be confirmed, the increased frequency of neoplasms after sub carcinogenic doses of BP and exposure of mice to microwaves indicates that long term exposure in non thermal MW fields may promote development of neoplasms that normally would not reach the clinically detectable stage, independently of the underlying mechanism.

In summary, long term exposure of mice to 2450MHz microwaves resulted in acceleration of the appearance and growth of tumours initiated by three different carcinogens, and a higher risk of cancer development in animals exposed to sub carcinogenic doses of initiators. the results suggest a tumour - promoting activity of the radiation but the cause of these phenomena still remains an open question. [132]

Szmigielski stressed that 2450 MHz is the resonant frequency for mice and the situation may be different in larger animals and human beings. Nevertheless evidence of accelerated development of cancers following microwave exposure is hardly a sound basis for increasing the permissible exposure limits by a 10.

Looking beyond the animal evidence suggesting a cancer promoting activity of radiofrequency waves there are also recent human population studies in which findings of elevated cancer rates have been associated with exposures to the radiofrequency part of the spectrum.

HUMAN EVIDENCE OF CANCER PROMOTION ACTIVITY

Robinette and Silverman studied the long term health outcomes of US Navy personnel exposed to radar.[132] No significant differences were found between the high and low exposure groups for malignant neoplasms as the cause of hospitalisation and or death.

However when three sub-groups of the high exposure group were developed to provide a gradient of potential exposure, a trend appeared for increased number of malignant neoplasms of the nervous system in the sub group rated as highly exposed.

Stronger human evidence of excessive cancers among microwave exposed personnel comes from two Polish studies conducted by Dr Stanislaw Szmigieliski of the Centre for Radiobiology and Radioprotection in Warsaw.

The first of these studies was a retrospective study on neoplasm mortality in Polish military career personnel. The total population of career service men was analyzed and a sub group of personnel occupationally exposed to microwaves and radiofrequency (on the basis of service records) was developed.

The exposed group amounted to 3% of the total military population. The rest, 97% were considered as subjects without exposure.

The exposed group was composed of personnel working on production, repair and use of devices emitting microwave and radiofrequency radiation, as well as those engaged in teaching and research with use of microwaves and radiofrequency radiation.

The accuracy of occupational exposure in the exposed group was determined on the basis of past and current service records, and on medical records which contained the results of periodic examinations that were introduced in Poland in 1968 for all servicemen exposed to these forms of radiation. The extent of daily exposure, power density, frequency and modulation varied with each individual in the exposed group. In general exposures to various types of radar radiation predominated but exposures to extremely low frequency were also noted. For microwave radiations, a typical exposure was estimated as 4 - 8 hours daily at power densities below 0.2 mW/cm² (safety zone according to

rules operating in Poland with incidental (several minutes daily exposures at 0.2 - 1 mW/cm²).

However mainly in personnel working on production and repair of microwave devices, incidents of short lasting exposures to higher power densities (estimated up to 10 - 20 mW/cm²) were reported. These exposures resulted from defying the safety rules and were difficult to evaluate. The high intensity exposures were more frequent in the 1960's, when the safety rules were not yet strictly enforced but still occurred in the 1970's, despite awareness of the possible hazards of MW/RF radiation. Thus in practice it was not possible to estimate precisely the intensity of MW/RF exposures for the whole exposed group due to large individual differences. We divided the exposed subjects into 5 classes, below 2 years, 2 - 5, 5 - 10, 10 - 15 and above 15 years of exposure.

Analysis of cancer morbidity was performed for 1971 - 80.

Twelve kinds of neoplasms were differentiated and for neoplasms originating in the hemato-lymphatic organs 6 types of diagnosis were analysed. In the exposed group which was about 3% of the total population about 8.8% of all the neoplasms appeared ... This means that the frequency of neoplasms was about 3 fold higher than expected in the exposed group ($P < 0.05$). The morbidity rate for the non exposed group was 64.2 cases of various neoplasms per 100000 per year at all ages analysed while in the exposed group it was 192.2 cases/100000/year. Organ localisation of the neoplasms revealed that the differences between exposed and non exposed depended mainly on the higher number of neoplasms in oesophagus, stomach, colo-rectal region, skin, thyroid gland and most of all neoplasms originating from hemato - lymphatic organs. The morbidity rate for all hemato - lymphatic neoplasms was found to be 7.4 cases/100000/year for the non exposed group and 50.8 cases/100000/year in the exposed group, the last being about 7 times higher compared with the non exposed group....

Because hemato-lymphatic malignancies were the most frequent diagnosis in the exposed group we analysed these neoplasms in more detail.

It was found that in the exposed group a higher frequency of lymphatic sarcomas and other lymphomas but not malignant lymphogranulomatosis, acute lymphoblastic leukemia at a younger age, and chronic and acute myelocytic leukemias were found, while the morbidity rate for chronic lymphatic leukemia, as well as for malignant lymphogranulomatosis did not

differ for all age groups but appears earlier in the exposed group at age 40 - 49 instead of 50 - 59.

Analysis of the morbidity rates for the four developed age groups (20 - 29, 30 - 39, 40 - 49 and 50 - 59) showed that the largest difference occurred at 40 - 49 years. In the non exposed personnel, the frequency of neoplasms (all kinds) did not reach 50 cases/100000/year while in the exposed group a rate of about 350/100000/year was found. In all other age groups the differences in morbidity were also statistically significant, but not as spectacular as that in the 40 - 49 group. There was also a high correlation of period of exposure to MWIRF fields with the morbidity rate of neoplasms and with the coefficient of linear correlation for all cases of malignancies all age groups, and all five classes of period of exposure ($r = 0.87$). The relation of cancer morbidity rate to period of exposure is best seen in the 40 - 49 year age group where there were about 70 cases/100000/year for those working in MWIRF environment for 2 - 5 years about 390 cases/100000/year for those working 5 - 10 years and about 450 cases/100000/year for those working 10 - 15 years in the fields. A relatively lower morbidity rate in this group (40 - 49 years) for personnel working above 15 years in the MWIRF environment about 270 case/100000/year seems to result from two causes. First, most of the personnel at the age of 40 - 49 had a 5 - 15 year period of exposure to MWIRFs, and thus the group with exposure duration more than 15 years was relatively small in terms of cancer morbidity rates. Second, at age 40 - 49 many subjects avoided work with MWIRFs and moved to other duties (command, administration) and, although still listed in the exposed group due to past exposures, the exposures no longer continued.

In summary, from a retrospective study that covered a large and well controlled population with a known population of subjects, and that had a relatively long period of observation (1971 - 80) the following conclusions may be drawn:

The risk of developing clinically detectable neoplastic disease was about three times higher for personnel exposed occupationally to MWIRF radiations. The highest risk appeared for malignancies originating from the hemato - lymphatic system (morbidity about 7 times higher). Other more frequent

neoplasms were located in the alimentary tract and in skin (including melanomas).

The highest risk factor of cancer morbidity related to occupational exposure to MW/RFs appeared for subjects at the age of 40 -49 who had a 5 - 15 year period of exposure

Morbidity rates of neoplasms in personnel exposed occupationally to MW/RFs showed strong correlation with the period of exposure

Neoplasms of the same localisation and or type developed earlier (by about 10 years) in personnel exposed occupationally to MW/RFs than in those not working in the MW/RF environment. [133]

Szmigielski describes these findings as *intriguing and disturbing for epidemiologists, medical officers, as well as for society as a whole* and goes on to acknowledge that there are limitations in this research:

despite the correlations found and the correlation co -efficients, they do not provide certain evidence of a causative relationship between the effect and the factor investigated. [134]

Szmigielski commenced a prospective study of the same population in the late 1980's

In this follow up prospective study still running at the time of writing Szmigielski reported,

Preliminary results available after a 1.5 year period support our earlier findings from retrospective studies, indicating higher morbidity of all malignancies especially of certain forms of leukemia and lymphatic neoplasms with relation to duration and intensity of RF/MW exposure. [135]

At the three year mark he again confirmed the increases in cancers among the exposed personnel.

Thus, it cannot be prudent to propose a ten fold increase in the allowable exposure limits and to generally make standards less stringent in the light of this.

GENERAL POPULATION STUDIES

There have been very limited attempts to study a relationship between radiofrequency radiation and elevated cancer rates among the general population. The problems of separating out other contributing agents are considerable in such studies but where it has been carried out, significantly elevated cancer rates, leukemias and certain lymphomas, have been found in populations in two states of America, Hawaii and Oregon, in population census tracts which have TV and FM radio broadcasting antenna located in them. Population Census tracts which did not have any such broadcasting antenna did not record any excess cancers.[136. 137]

In the face of these further human findings I say yet again it cannot be prudent to propose a ten fold increase in the radiation exposure limits for the general population. Indeed a reduction in exposures for the general population was considered desirable by CSIRO's Dr David Hollway when the standard was first promulgated and with the passage of only a few years may have already been vindicated.

CONCLUSION

While there is no operational need to increase the human exposure limits, neither for occupational or non occupational exposures and while there is increasing evidence of harm to human health from weak electromagnetic fields no increase can be supported.

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